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Particle Acceleration in Cislunar Space

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The recent discovery¹ of a characteristic red luminescence when enstatite achondrites are bombarded by 40 kev protons led Kopal and Rackham^{2,3} to observe the moon in order to determine whether a similar luminescence might be excited in lunar materials by solar wind bombardment. On the night of Nov. 1-2, 1963, Kopal and Rackham observed an enhanced red emission from the vicinity of the crater Kepler. The duration of the red glow was of the order of ten minutes or longer, and it appeared twice within a two-hour period. No repetition of this phenomenon was observed on the following night or at the next lunation.

Among the circumstances which may be relevant to an explanation of this phenomenon are the following: The enhanced emission took place within one day of full moon. There had been a class 3 solar flare on October 28 and two class 1 flares on November 1, and the earth was in a magnetically-disturbed region of space. Cosmic ray neutron counts indicated that recovery from a Forbush decrease was taking place at

the time of the lunescence.

Kopal and Rackham² noted that the red glow from the Kepler region approximately doubled the brightness of the lunar surface there, so that the amount of energy emitted in the red was approximately 10^4 ergs/cm² sec. They further concluded² that, since the highest luminescent efficiency (in the Bustee meteorite) had been found to be 20 per cent¹, it was likely that the incoming energy responsible for the luminescence was at least 5×10^4 erg/cm² sec. The other two enstatite achondrites examined by Derham and Geake¹ had a luminous efficiency lower by a factor of three, so it is not unlikely that the incident energy exceeded 10^5 erg/cm² sec. Because approximately the same luminous efficiency is found during bombardment of the meteorite powder by photons of several mev as by protons of 40 kev⁴, it appears likely that the above conclusions are not sensitive to the energy of the particles bombarding the lunar surface.

Kopal and Rackham² have discussed a possible interpretation that the above events resulted from bombardment of the lunar surface by an enhanced flow

of solar plasma initiated by the preceding solar activity. They noted that the energy flux required was five orders of magnitude greater than that normally available in the solar wind, which must be considered a difficulty. Kopal⁴ has suggested that an alternative mechanism might be required in which the lunar bombardment would involve particles, of energy greater than those of the solar wind, which had been accelerated in the preceding class 3 flare and trapped by the chaotic magnetic field configuration then existing in interplanetary space. It is the purpose of the present communication to suggest a further alternative.

The region of interaction between the solar wind and the earth's magnetosphere is very complex, but the following general picture has emerged (see for example Hines⁵). In the solar direction the pressure of the solar wind compresses the magnetosphere, but the solar wind must then flow around the magnetosphere, so that in the antisolar direction a long cavity is formed into which the terrestrial magnetic field can expand. Quite large energetic particle fluxes are observed near the magnetosphere boundary in the antisolar direction, and

it has been suggested that the region of trapped radiation may extend to a distance comparable to that of the moon⁶. A recent analysis of terrestrial magnetic activity has shown that the general level of activity is slightly changed for several days on either side of full moon, suggesting that the antisolar magnetic cavity may extend to the lunar distance⁷. Since the solar wind exhibits supersonic flow with respect to the earth, it is necessary that a standing shock wave must be formed beyond the magnetopause. The highly turbulent magnetic fields between the shock front and the magnetopause have been observed⁸.

It seems to be the case that wherever turbulent fluid motions and chaotic magnetic fields exist in nature, the acceleration of charged particles to energies much exceeding thermal energies takes place. This is inferred to be the case in strong extragalactic radio sources, in supernova remnants, in solar flares, and in the magnetosphere itself. One acceleration mechanism which can be very efficient in certain circumstances is the second-order acceleration of charged particles traversing time-varying fluctuations in a magnetic

field system⁹. This is probably responsible for the acceleration of particles in the outer part of the magnetosphere which are then dumped directly into the atmosphere to produce auroras. The process will be enhanced at times of greater magnetic activity when the solar wind is exerting varying pressure on the magnetopause.

It is a logical extension of these considerations to expect that extensive particle acceleration will take place in the shock zone beyond the magnetopause. The particles thus accelerated will be discharged down the magnetic field lines in the antisolar direction. By analogy with the auroral discharges, it is possible that the particle beams in the antisolar direction may carry an energy flux large compared to that in the solar wind. However, since the energy going into the charged particle beams must be derived from that of the solar wind, it is evident that such particle streams will be isolated in local regions of space, and that the integrated energy flux of plasma and particles together cannot exceed the initial energy flux of the plasma flow.

The luminescence near the crater Kepler observed

by Kopal and Rackham may have been produced by these energetic particle streams. It may also have been produced by trapped radiation in the distant tail of the magnetosphere. Many more observations will be needed to evaluate the plausibility of these two possibilities. In either case such luminescence can be expected to occur principally at times near full moon and during unusually large magnetic activity on the earth. Because of the localized nature of the incident particle streams, lunar luminescence excited in this way is likely to be observed only in small regions of the moon at any one time and to exhibit variations with periods of a few minutes.

Because of the complex character of the phenomena suggested here, it is not possible to suggest the range of energies to which particles are likely to be accelerated in the shock zone, and hence it is not clear whether such particle streams will constitute a radiation hazard to a manned lunar landing or to manned spaceflight in the antisolar direction.

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